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Progressive Damage and Fracture of a Particulate Composite

C.T. Liu[1]

Abstract

In this study, the local damage mechanisms and strain fields near the crack tip as well as the crack growth behavior in an centrally-cracked sheet specimen was investigated. The specimen was made of a particulate composite material containing hard particles embedded in a rubbery matrix and it was subjected to a constant strain rate of 0.5 min^{-1} at room temperature. The effects of the applied strain level on the local damage and fracture processes as well as the strain fields near the crack tip were investigated and the results are discussed.

Introduction

An important engineering problem in structural design is evaluating structural integrity and reliability. It is well known that structural strength may be degraded during its design life due to mechanical or chemical aging, or a combination of these two aging mechanisms. Depending on the structural design, material type, service loading, and environmental condition, the cause and degree of strength degradation due to the different aging mechanisms differs. One of the common causes of strength degradation is the result of crack development in the structure.

When cracks occur, whether resulting from the manufacturing process or from service loads, the stresses near the crack tip will be redistributed according to nonlinear material behavior. Depending on the magnitude of the local stresses and the local strength, various defects, microvoids or microcracks, can develop in the

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crack tip region. And, depending on the severity of these defects, crack growth behavior can be significantly affected. Therefore, to obtain a fundamental understanding of crack growth behavior in particulate composite materials, the effect of the defect on local fracture behavior near the crack tip needs to be determined.

In recent years, a considerable amount of work has been done studying crack growth behavior in particulate composite materials [1-4]. This work was based on linear viscoelastic fracture mechanics. The principles of classical fracture mechanics are well established for single phase materials. However, experimental evidence indicates that linear fracture mechanics theories have been applied to particulate composite materials with varying degrees of success.

In this study, centrally cracked specimens (Fig. 1) were used to study local damage near the crack tip and crack growth behavior in a particulate composite under constant strain rate (0.5 min^{-1}) at room temperature. The specimens were made of a highly filled polymeric material, containing hard particles in a rubbery matrix. Prior to testing, the specimens were conditioned at the test temperature for one hour and were then tested at the constant strain rate until the specimen fractured. During the test, photographs were taken at given time intervals and used to determine local damage and fracture mechanisms near the crack tip as well as crack growth behavior in the material.

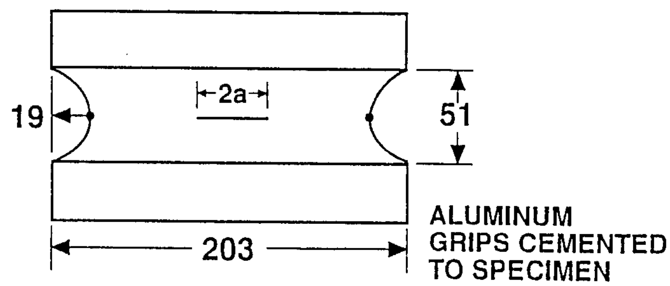
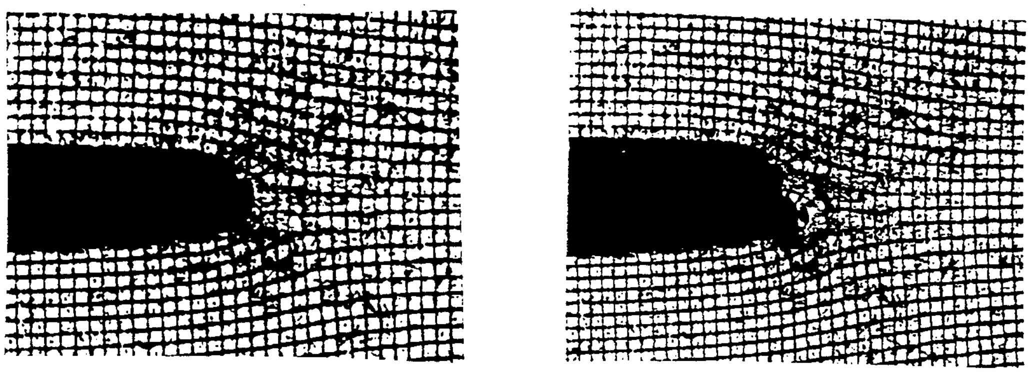


Figure 1. Specimen Geometry

Results and Discussion

It is well known that, on the microscopic scale, a highly filled polymeric material can be considered an inhomogeneous material. When these materials are stretched, the different sizes and distribution of filled particles, the different crosslink density of polymeric chains, and the variation in bond strength between the particles and the binder can produce highly nonhomogeneous local stress and strength fields. Depending on the magnitude of the local stress and the local strength, damage can be developed in the material, especially near the crack tip region. The damage developed in the material may be in the form of microvoids or microcracks in the binder or dewetting in the between the binder and the filler particles. Damage growth in the material may occur as material tearing or as successive nucleation and coalescence of the microcracks. These damage processes are time dependent and are the main factor responsible for the time sensitivity of strength degradation as well as the fracture behavior of the material. Therefore, obtaining a better understanding of crack growth behavior requires detailed knowledge of damage mechanisms in the crack tip region.

A typical set of photographs showing the crack surface profile and local damage showing the opening and crack growth in the specimen is shown in Figure 2. According to Figure 2, crack tip blunting occurs both before and after crack growth. Due to the heterogeneous nature of the highly filled polymeric material, the degree of blunting varies with the position of the advancing crack tip. This suggests that the local microstructure, or local material damage, near the crack tip plays a significant role in the blunting phenomena. Figure 2 also reveals that local damage can be developed in a small region near the crack tip. This damaged region may be defined as the failure process zone in which the material has disintegrated into ligament form or becomes porous. Damage growth in the failure process zone may occur by tearing or by successive nucleation and coalescence of the small voids. The successive coalescence of the main crack tip with the void near the crack tip leads to a small distance. It is interesting to point out that the size of the failure process zone and the intensity of damage in the failure process zone vary with time. This phenomenon is similar to the crack tip blunting phenomenon mentioned earlier.



a. Prior to Crack Growth

b. After Crack Growth

Figure 2. Crack Tip Profiles

Typical plots of crack growth versus time are shown in Figure 3. The data reveal that the crack does not grow in a continuous and smooth manner. It appears that the crack growth rate undergoes irregular fluctuations. In other words, the crack growth process consists of a slow-fast-slow phenomenon.

A typical distribution of the normal strain is shown in Figure 3. Figure 3 shows that the strain distribution is highly irregular. Although it is believed that a portion of the irregularities stems from an experimental error, the irregularities are primarily due to the nonhomogeneity of the material. The experimental data indicate that large strains occur in a small region approximately less than 1.0 mm ahead of the crack tip.

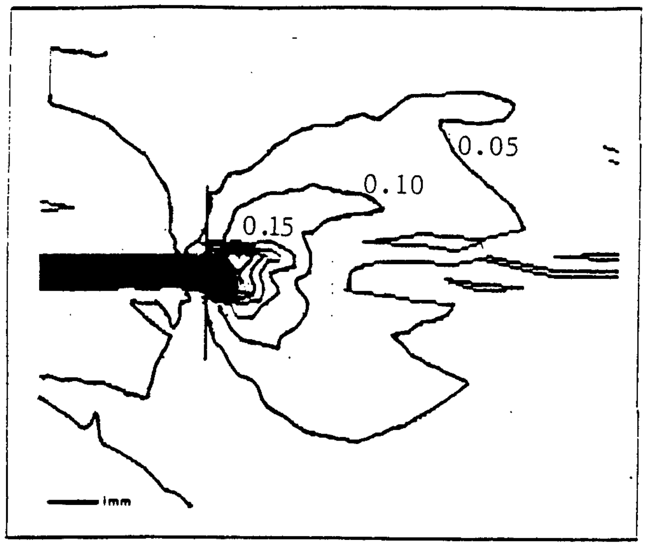


Figure 3. Contour Map of Normal Strain (Prior to Crack Growth)

Conclusions

In this study, local damage mechanisms and strain fields near the crack tip as well as crack growth behavior in a particulate composite material were investigated. Experimental results indicate that a material's microstructure has a large effect on the strain distribution near the crack tip. In the highly strained regions, material may be damaged and voids may develop and the crack grew by the coalescence of the voids with the crack tip. The crack-damage interaction in a contributing factor to the fluctuation of the crack growth behavior. Experimental results also indicate that crack tip bluntings occur during the loading process and the crack growth consists of a blunt-growth-blunt phenomenon which appears to be highly nonlinear.

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